

10.0400

A

JC890 U.S. PTO

**UTILITY PATENT APPLICATION TRANSMITTAL
(Large Entity)***(Only for new nonprovisional applications under 37 CFR 1.53(b))*Docket No.
BUR9-2000-0024-US1Total Pages in this Submission
3**TO THE ASSISTANT COMMISSIONER FOR PATENTS**Box Patent Application
Washington, D.C. 20231

Transmitted herewith for filing under 35 U.S.C. 111(a) and 37 C.F.R. 1.53(b) is a new utility patent application for an invention entitled:

METHOD OF POWER DISTRIBUTION ANALYSIS FOR I/O CIRCUITS IN ASIC DESIGNS

and invented by:

**Gary S. Ditlow
Robert A. Proctor**If a **CONTINUATION APPLICATION**, check appropriate box and supply the requisite information:☐ **Continuation** ☐ **Divisional** ☐ **Continuation-in-part (CIP)** of prior application No.: _____

Which is a:

☐ **Continuation** ☐ **Divisional** ☐ **Continuation-in-part (CIP)** of prior application No.: _____

Which is a:

☐ **Continuation** ☐ **Divisional** ☐ **Continuation-in-part (CIP)** of prior application No.: _____

Enclosed are:

Application Elements

1. ☒ Filing fee as calculated and transmitted as described below
2. ☒ Specification having 17 pages and including the following:
 - a. ☒ Descriptive Title of the Invention
 - b. ☐ Cross References to Related Applications *(if applicable)*
 - c. ☐ Statement Regarding Federally-sponsored Research/Development *(if applicable)*
 - d. ☐ Reference to Microfiche Appendix *(if applicable)*
 - e. ☒ Background of the Invention
 - f. ☒ Brief Summary of the Invention
 - g. ☒ Brief Description of the Drawings *(if drawings filed)*
 - h. ☒ Detailed Description
 - i. ☒ Claim(s) as Classified Below
 - j. ☒ Abstract of the Disclosure

JC932 U.S. PTO
09/677013

10/03/00

UTILITY PATENT APPLICATION TRANSMITTAL (Large Entity)

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Docket No.
BUR9-2000-0024-US1

Total Pages in this Submission
3

Application Elements (Continued)

3. ☒ Drawing(s) (when necessary as prescribed by 35 USC 113)
- a. ☒ Formal Number of Sheets 7
- b. ☐ Informal Number of Sheets _____
4. ☒ Oath or Declaration
- a. ☒ Newly executed (original or copy) ☐ Unexecuted
- b. ☐ Copy from a prior application (37 CFR 1.63(d)) (for continuation/divisional application only)
- c. ☒ With Power of Attorney ☐ Without Power of Attorney
- d. ☐ DELETION OF INVENTOR(S)
Signed statement attached deleting inventor(s) named in the prior application,
see 37 C.F.R. 1.63(d)(2) and 1.33(b).
- ☐ Incorporation By Reference (usable if Box 4b is checked)
The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under
Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby
incorporated by reference therein.
- ☐ Computer Program in Microfiche (Appendix)
- ☐ Nucleotide and/or Amino Acid Sequence Submission (if applicable, all must be included)
- a. ☐ Paper Copy
- b. ☐ Computer Readable Copy (identical to computer copy)
- c. ☐ Statement Verifying Identical Paper and Computer Readable Copy

Accompanying Application Parts

8. ☒ Assignment Papers (cover sheet & document(s))
9. ☐ 37 CFR 3.73(B) Statement (when there is an assignee)
10. ☐ English Translation Document (if applicable)
11. ☒ Information Disclosure Statement/PTO-1449 ☒ Copies of IDS Citations
12. ☐ Preliminary Amendment
13. ☒ Acknowledgment postcard
14. ☒ Certificate of Mailing
- ☐ First Class ☒ Express Mail (Specify Label No.): EK782889465US

UTILITY PATENT APPLICATION TRANSMITTAL (Large Entity)

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Docket No.
BUR9-2000-0024-US1

Total Pages in this Submission
3

Accompanying Application Parts (Continued)

15. ☐ Certified Copy of Priority Document(s) (if foreign priority is claimed)

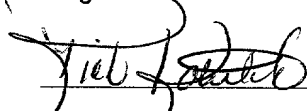
16. ☐ Additional Enclosures (please identify below):

Fee Calculation and Transmittal

CLAIMS AS FILED

For	#Filed	#Allowed	#Extra	Rate	Fee
Total Claims	15	- 20 =	0	x \$18.00	\$0.00
Indep. Claims	5	- 3 =	2	x \$78.00	\$156.00
Multiple Dependent Claims (check if applicable) <input type="checkbox"/>					\$0.00
BASIC FEE					\$710.00
OTHER FEE (specify purpose)					\$0.00
TOTAL FILING FEE					\$866.00

- ☐ A check in the amount of _____ to cover the filing fee is enclosed.
- ☒ The Commissioner is hereby authorized to charge and credit Deposit Account No. 09-0456 as described below. A duplicate copy of this sheet is enclosed.
- ☒ Charge the amount of \$866.00 as filing fee.
- ☒ Credit any overpayment.
- ☒ Charge any additional filing fees required under 37 C.F.R. 1.16 and 1.17.
- ☐ Charge the issue fee set in 37 C.F.R. 1.18 at the mailing of the Notice of Allowance, pursuant to 37 C.F.R. 1.311(b).



Signature

Richard M. Kotulak
Registration No. 27,712
International Business Machines Corporation
Intellectual Property Law - Mail 972E
1000 River Street
Essex Junction, VT 05452
Phone: (802)769-4457

Dated: 10/3/00

CC:

APPLICATION
FOR
UNITED STATES LETTERS PATENT

APPLICANT NAME: Gary S. Ditlow
Robert A. Proctor

TITLE: METHOD OF POWER
DISTRIBUTION ANALYSIS FOR
I/O CIRCUITS IN ASIC DESIGNS

DOCKET NO: BUR9-2000-0024-US1

INTERNATIONAL BUSINESS MACHINES CORPORATION

METHOD OF POWER DISTRIBUTION ANALYSIS FOR I/O CIRCUITS IN ASIC DESIGNS

Gary S. Ditlow and Robert A. Proctor

CROSS REFERENCE TO RELATED APPLICATION

This application is related by common inventorship and subject matter to co-pending application titled "Method of Assigning Integrated Circuit I/O Signals in an Integrated Circuit Package". Until such time as the foregoing application is assigned a serial number by the U.S. Patent and Trademark Office, it may be referenced by the following applicant: Attorney Docket Nos.: BUR990226US1: 1806/103. The listed application is assigned to International Business Machines Corporation and is entirely incorporated herein by this reference.

BACKGROUND OF THE INVENTION

The present invention relates to a method for establishing a distribution of I/O circuits in an application-specific integrated circuit (ASIC), and more particularly to a method for insuring that a distribution of I/O circuits complies with voltage drop (IR) and electro-migration (EM) requirements for the ASIC.

In an ASIC, a power grid comprising a plurality of power buses supplies current to logic circuitry and I/O circuits used to drive signals on and off a chip housing the ASIC. In determining a distribution of the I/O circuits, IR (current x resistance) drops and EM limits on the chip design must be taken into consideration. For example, if I/O circuits are clustered too densely within a given area, IR and EM limits of the chip may be exceeded, causing a logic or electrical failure.

Power buses that supply power to I/O circuits also provide power to the logic circuitry of the chip, and consequently, for best accuracy, currents of the logical circuitry should be included in an analysis of IR and EM behavior of the chip.

Existing methods of performing analysis of the distribution of I/O circuits in chip design have disadvantages. For example, power distribution analysis is typically performed late in the overall design process. Most existing approaches utilize an extraction process. The extraction process extracts shape data from the geometric pattern

comprising the conducting lines in which current flows on a chip. The shape data is processed by extraction techniques to convert the shape data into a resistance matrix, which would then be solved. The extraction process is typically time-intensive and creates extremely large resistance models, which can take many hours or days to solve.

Moreover, existing methods tend to be overly localized. A designer may refer to guidelines, which recommend that circuits be placed in a certain density per unit area. However, such an approach fails to take into account the current requirements of the overall power distribution grid, and consequently can introduce inefficiencies in power distribution analysis. For example, guidelines that specify a maximum number of allowable I/O circuits within a specified area, but do not account for neighboring areas that maybe empty or occupied by low power circuits, thus demanding less current, typically force designers to adjust I/O circuits placement when a broader analysis may show that no placement changes are needed.

In view of the foregoing, a method for I/O circuit distribution analysis is needed which addresses the noted disadvantages of existing methods.

SUMMARY OF THE INVENTION

A method according to the present invention provides for an analysis of I/O circuit distribution which takes into account the overall power grid of an ASIC, and which may be performed early in the chip design process. The method results in improved accuracy of I/O circuit placement and a substantial reduction of the time required for analysis of I/O circuit placement as compared to existing methods.

In a preferred embodiment, the method comprises calculating currents corresponding to the I/O circuits of an ASIC, and generating a resistance model of a power distribution network for the ASIC. Using a distribution of the I/O circuits in terms of their assigned locations within the chip, each I/O circuit is indexed to the node closest to it in the resistance model. The average logic current demand per node is also calculated and indexed to the nodes.

The resulting resistance and current source model is then solved using a known solver. The solver outputs voltages of each node of the resistance/current model. The voltages are then checked against the design specifications to determine whether they are

within IR and EM limitations. A report identifying those nodes which are not in compliance with requirements is produced and may be used to re-distribute the I/O circuits in order to satisfy IR and EM limitations. The foregoing process may be performed iteratively to arrive at a distribution of I/O circuits which satisfies design requirements.

The above-described method allows a detailed analysis of IR and EM behavior of an I/O circuit distribution to be performed very early in the design cycle by requiring only minimum design-specific information, comprising an image definition of an ASIC with defined locations of I/O circuits and a known resistance model of a power distribution network for the ASIC. The analysis takes into account the entire power distribution network. Accordingly, problem areas can be identified early in the design process and solved using the above-described iterative approach. The method can also be applied in later stages of design, as more detailed information becomes available.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows an example of an area-array type of ASIC chip layout;

Figure 2 shows an example of a peripheral type of ASIC chip layout;

Figure 3 shows an example of a portion of a power bus in a power distribution network for an area-array type chip layout, including example I/O circuit placements and connections;

Figure 4 shows a resistance model corresponding to the power buses and connected I/O circuits of Figure 3;

Figure 5 shows an example of a portion of a peripheral chip layout, with detail of ground bus connections;

Figure 6 shows a resistance model corresponding to Figure 5;

Figure 7 shows a process flow according to the invention; and

Figure 8 shows a general purpose computer system for practicing the method of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Figures 1 and 2 show examples of types of ASIC chip layouts to which the method according to the present invention may be advantageously applied. Figure 1 shows an example of an area-array type chip layout. A chip 100 includes a logic area 101 containing logic circuits. The chip may also contain macros 102, which are pre-defined areas of logic already placed and routed.

Multiple chip layers are illustrated in the same plane in Figure 1. The logic circuits and macros would typically reside on a lower layer. I/O circuits 103 for carrying signals on and off the chip may be distributed across the logic area, anywhere within snap grids defined for the I/O circuits. The snap grids are typically aligned with the major horizontal and vertical power buses of the power distribution network for the chip. A routed connection 105 may exist between an I/O circuit 103 and an I/O pad 104. The I/O pads 104 typically occupy an upper metal layer of the chip. The routed connection 105 is made between routing layers of metallurgy M1 to M6. The I/O pads 104 illustrated in Figure 1 are signal pads; no power pads are shown.

Figure 2 shows an example of a peripheral type of chip layout. In a peripheral type of layout, I/O circuits 103 are peripheral to a logic area 101. Each I/O circuit 103 resides in an "I/O slot" electrically connected by a connection 105 to an I/O pad 104. In Figure 2 multiple chip layers are illustrated in the same plane. The I/O pads 104 would typically occupy an upper metal layer of the chip. The I/O pads 104 illustrated in Figure 2 are signal pads; no power pads are shown.

Referring to Figure 3, there is shown a portion of a power distribution network for the area-array type of chip layout illustrated in Figure 1. The power distribution network would typically comprise a plurality of vertical and horizontal power buses. The arrangement of the power buses establishes a regular, repeating pattern for the power distribution network. Points along the power buses, including points where the vertical buses intersect the horizontal buses, may be defined as nodes of the power distribution network. Each node has a unique X,Y coordinate (where X and Y refer to orthogonal axes in a coordinate system for defining locations on the chip).

The portion of the power distribution network comprises horizontal conductors on a M5 metal layer, having alternating VDD and GND voltage levels, designated by

reference characters E1 through E10. Vertical conductors on a M4 metal layer are designated D1- D16, and vertical conductors on a M6 metal layer are designated F1-F4. Also shown are power pad connections (VDD and GND “C4” pads), M5-M6 vias, and M4-M5 GND nodes.

Three I/O circuits 103.1-3 are shown. The I/O circuit designated 103.1 has a connection to the GND voltage level at E5-D3, a connection to the VDD voltage level at E4-D3, a connection to the GND voltage level at E3-D3, and a connection to the VDD voltage at E2-D3. The I/O circuit designated 103.2 has connections to the power distribution network at E5-D4 (GND), E4-D4 (VDD), E3-D4 (GND), and E2-D4 (VDD). The I/O circuit designated 103.3 has connections to the VDD voltage level at E10-D8 and E8-D8, and connections to the GND voltage level at E9-D8 and E7-D8.

According to the invention, a resistance model is created corresponding to the power distribution network for the area-array type chip layout as illustrated in Figures 1 and 3. A computer program taking as input information files describing technical details of the power distribution network may be executed to generate the resistance model, as described in greater detail below. The resistance model is defined in terms of the resistivity of the power buses at nodes of the buses. The resistivity may be calculated, for example, using a known sheet rho and a width of the bus.

Currents in the I/O circuits 103 connected to the buses are calculated and included in the resistance model. In including the I/O currents in the resistance model, a known X-Y location of the I/O circuit in the power distribution network is used to index, or logically relate, the currents for the I/O circuits with the node in the resistance model closest to the I/O circuit. An average logic current demand per node is calculated and indexed to the nodes.

The resistance model with corresponding I/O circuit currents is then solved by a commercially available solver to find voltages at the nodes. The output of the solver may comprise a file identifying each node and the voltage at that node, and a file describing each element of the resistance/current model, the voltage at each end of the element, and the current flowing through the element.

The output of the solver is compared against a specified allowable voltage distribution, to check whether the distribution of I/O circuits is within IR and EM

restrictions. For example, a design rule may specify that no circuit may have a variation of greater than 5 percent of a voltage supplying the circuit. Using the known supply voltages of the chip, and the 5 percent allowable variation which can be calculated, IR compliance for the I/O circuit distribution can be determined. Similarly, using the currents through each element output by the solver, compliance with EM restrictions can be determined.

Typically, the output of the solver would be formatted into a human readable file that reports the voltages and currents and any violations of IR or EM limits. If the report showed violations of IR or EM limits, the distributions of I/O circuits would be rearranged, and again processed as described above to check for compliance with the IR and EM limits.

In the step of constructing the resistance model of the power distribution network, techniques may be applied for achieving greater processing efficiency. For example, a section of the network may represent a pattern that is repeated across the network, and therefore, the resistance model can be constructed by simply repeating the resistive elements of this section in a regular fashion to model the entire network.

Moreover, the resistance model may be expressed in different degrees of granularity. Typically, different levels of granularity would yield different X-Y locations for nodes of resistance model. For example, in a model of fine granularity, each I/O circuit would be closer to at least one node of the resistance model than would be the case, for the average I/O circuit, in a resistance model of coarse granularity. The degree of granularity utilized would depend upon the accuracy of the model needed in order to achieve acceptable results as determined by a user.

One example of a simplified resistance model that would permit greater processing efficiency while still achieving acceptable results is a resistance model in which the resistance values for the metal layers are lumped. The metal layers M1 through M6 comprise horizontal buses extending in the X direction across layers M1, M3 and M5, and vertical buses extending in the Y direction on layers M2, M4, and M6. Vias form layer-to-layer bus connections. In a simplified model for greater processing efficiency, resistance values of the M1 and M3 layers could be combined or lumped into the M5 layer, while the resistance values of the vertical M2 layer could be lumped into

the vertical M4 layer. Such a lumped model could provide a suitable level of accuracy, while allowing for a greater processing speed in constructing and solving the resistance model.

The step of calculating the currents of the I/O circuits for incorporation into the resistance model includes two forms of analysis. One form is an IR, or voltage drop analysis. A second form of analysis calculates EM, or electromigration currents. IR analysis uses average currents for the logic circuitry and maximum currents for the I/O circuits. EM analysis uses average currents for the logic circuitry and average currents for the I/O circuits.

To calculate the maximum currents for the IR drop analysis, a file containing specifications for the I/O circuits may be utilized. The file would include such information as the impedance of the I/O circuits, the X-Y locations of the circuits, and the I/O pad to which the I/O circuit is connected. Typically, such specifications would differ depending upon the type of I/O circuit and chip technology. Using the I/O specifications for the I/O circuits, a maximum current utilized by each I/O circuit is calculated. Such maximum currents typically occur when an I/O circuit is driving a signal on or off a chip, which requires a significant amount of current. These high currents generate the IR drops which are of interest.

For calculating the average current demand of the logic circuitry, a calculation as follows may, for example, be made: $\text{logic current at each node} = (\text{ASIC power} - \text{I/O circuit power}) / (\text{supply voltage} \times \text{number of nodes in the resistance model})$. Using representative values for ASIC power of 20 watts, I/O circuit power of 8 watts, supply voltage of 2.5 volts and a number of nodes in the resistance model equal to 40,000, an average current demand for the logic circuitry at each node could be, for example, 0.12 ma.

For the EM analysis, an average current for the I/O circuits is also calculated using the I/O specifications. In performing the EM analysis, for greater accuracy in the resistance/current model, the current of the logic circuitry of the chip is factored in. The current used by the logic circuitry, which typically includes such elements as inverters, multiplexors, latches and Boolean logic gates, is typically smaller than the currents utilized by the I/O circuits, but affects the EM analysis.

The invention is not limited to calculating DC current values. Typically, the solver includes the capability of calculating time dependent sources for I/O circuits that model differences of slew rates and non-simultaneous switching between circuits.

As discussed above, the calculated maximum currents and average currents are indexed, or logically related, to nodes in the resistance model. As the design of the overall ASIC progresses and actual current demands of the logic circuitry become known, as opposed to a calculated average, these could be indexed to the resistance model for greater accuracy.

Figure 4 shows an example of a resistance model with I/O circuit currents indexed to nodes that correspond to the portion of the power distribution network shown in Figure 3. Nodes 400 of the resistance model are shown as points at which discrete resistors, collectively representing the resistivity of the buses of the power distribution network, are connected. The I/O circuits 103.1, 103.2 and 103.3 of Figure 3 are modeled as current sources and resistances and indexed to the nodes defined in the resistance model, which correspond most closely to the X-Y locations of the I/O circuits in the power distribution network.

Once a resistance model of the power distribution network has been derived and current sources corresponding to the I/O circuits and logic circuitry have been indexed to nodes in the resistance model as shown in Figure 4 (logic circuitry currents not shown), the resistance model is solved for voltages at the nodes. The model may be solved by any suitable commercially available matrix solver, for example, the Yorktown sparse matrix RLC solver. A more typical resistance model than the model shown in Figure 4 would comprise tens or hundreds of thousands of nodes, interconnected resistors, current sources and voltage sources.

In an embodiment, the resistance model with indexed currents would be formulated as matrix equations in the form $\mathbf{GV} = \mathbf{I}$. The unknowns being solved for are the node voltages \mathbf{V} . The conductance matrix \mathbf{G} corresponds to a nodal formulation satisfying Kirchhoff's current law. The right hand side vector \mathbf{I} models the current sources for the I/O circuits and average logic current demand. A typical solver would factor the symmetric \mathbf{G} matrix using a Cholesky decomposition \mathbf{LL}^T . The voltages \mathbf{V} would then be computed using forward elimination and back solve.

In constructing the resistance model to be input to the solver, the nodes are named using a naming convention which preserves the X-Y location information during the solving, for example, by naming the nodes after rows and columns of the resistance model. As discussed above the solver would produce files detailing voltages at each node and currents through each element of the resistance model. The files would then be analyzed to identify violations of defined IR and EM limits.

Figure 5 shows the physical layout of a portion of a power distribution network for a peripheral layout as illustrated in Figure 2. The layout comprises M1-M3 horizontal buses and M2-M4 vertical buses intersecting at nodes 500 within the logic region 101.

The buses connect to peripheral power buses which parallel the edges of the die and pass over the I/O circuits. There are occasional GND pads (two are shown) which connect to GND, supplied throughout the module. Figure 5 shows only the GND buses. There is a similar bus structure for VDD that runs in parallel with the GND buses shown in Figure 5. The VDD bus structure is not shown for greater clarity

Figure 6 shows a representation of the resistance model corresponding to the power distribution network of Figure 5 which would be generated according to the invention, with the currents 600 of the logic circuitry and I/O circuits (cells) indexed to their corresponding nodes. This model is solved by a matrix solver and a report is produced as described above.

Figure 7 shows a process flow according to an embodiment of the invention. Input file 700 is an I/O specification file containing data describing an initial X-Y placement of the I/O circuits and their connections to the power distribution network of the chip, as illustrated, for example, in Figure 3. The I/O specification file also contains such information as the impedance of the I/O circuits, which I/O circuits are drivers and which receivers, actual current usage parameters such as duty cycle, switching factor and terminations., and the I/O pads to which the I/O circuits are connected.

Next the maximum and average I/O circuit currents are calculated as shown in block 701 using the information in the I/O specification file. The logic circuitry currents are also calculated. The calculation of the currents may also utilize technology files 702, which includes circuit design information such as capabilities and strength of circuits, and normal usage of currents.

A resistance model is then generated as shown in block 703, and the calculated currents are indexed to the corresponding closest node in the resistance model. An updated I/O circuit specification file 714, resulting from an earlier application of the method, may supply data describing revised X-Y locations of the I/O circuits.

5 The step of generating the resistance model also utilizes the technology files 702. The technology files would include such data as chip image data. The chip image data would correspond to a type of layout, for example, an area-array type layout or peripheral type layout as shown in Figures 1 and 2, and include resistance information for each routing (M1 - M6) layer of the chip. The chip image data further includes the locations and voltages of the power buses and pads. The bus information could be expressed as a bus starting location, a bus width, a repeat factor, and an end. As described above, this basic pattern can be used to map out the bus distribution and network across the extent of the chip to construct the resistance model corresponding thereto. Each horizontal and vertical layer of the power distribution network is described in the chip image data.

10 Block 703 produces the resistance model with indexed currents as shown in output file 704, and may also produce an I/O circuit data file 712 which is used in a step of checking for IR and EM violations and producing an output errata/log file 707, and may be used in a step of revising the placement of the I/O circuits if IR and EM violations are detected. The I/O circuit data arranges data types and related information into a tabular, easily-manipulated format for the convenience of the later processing.

15 Block 705 illustrates the solving of the resistance/current model. The solved model is checked for IR and EM violations as shown in block 706, and a human-readable errata/log report 707 detailing node voltages, currents and any violations is generated. As shown in block 708, if the check for violations detects any violations, the placement of the I/O circuits may be revised as shown in block 709 and used to generate an updated I/O circuit specification file 711. The updated I/O circuit specification file 711 is merged (block 713) with the initial placement file 700 to produce updated I/O circuit specification file 714. Otherwise, as shown in blocks 710, design may proceed to subsequent stages.

20 The updated I/O circuit specification 714 may be used, as shown in block 703, to correctly index the revised I/O circuit placements to their corresponding nodes in the

resistance model. The revised resistance/current model may be solved and checked again for violations. The foregoing process may be repeated until an error-free design is arrived at.

Figure 8 shows a high-level representation of a computer system for implementing a preferred embodiment of the present invention, such as might be realized by a variety of known and commercially available hardware and software elements as embodied, for example, a Unix™ workstation. The system comprises a memory 800 including a ROM and RAM, processor 810 and user interface 811 comprising a video display 812, keyboard 813 and mouse 814. Elements may communicate via system bus 806. The system may further be connected to a network 817 via a network medium 818 and network 815.

A computer program or a collection of programs comprising computer-executable instructions for performing method steps according to the present invention may be stored and transported on computer-usable media such as diskette 801, CD-ROM 802, magnetic tape 803 and fixed disk 804. To perform the steps of the method, the instructions may be retrieved from the computer-usable media 801 through 804 using their respective drives 805 through 808 into memory 800 and executed by a processor 810. The method disclosed hereinabove may find specific implementations in a variety of programming structures and data forms, which are considered to be within the abilities of a programmer of ordinary skill in the art after having reviewed the specification.

The foregoing description of the invention illustrates and describes the present invention. Additionally, the disclosure shows and describes only the preferred embodiments of the invention, but it is to be understood that the invention is capable of use in various other combinations, modifications, and environments and is capable of changes or modifications within the scope of the inventive concept as expressed herein, commensurate with the above teachings and/or the skill or knowledge of the relevant art. The embodiments described hereinabove are further intended to explain best modes known of practicing the invention and to enable others skilled in the art to utilize the invention as such, or other, embodiments and with the various modifications required by the particular applications or uses or the invention. Accordingly, the description is not

intended to limit the invention to the form disclosed herein. Also, it is intended that the appended claims be construed to include alternative embodiments.

100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000

What is claimed is:

1 1. A method for performing power distribution analysis for I/O circuits in an
2 integrated circuit (IC) design, said I/O circuits having defined placement locations within
3 a power distribution network of said design, comprising the steps of:

4 a) calculating maximum and average currents for each of said I/O circuits,
5 and an average logic current demand per node;

6 b) creating a resistance model of said power distribution network comprising
7 nodes and resistors corresponding to points on buses of said network and resistivities
8 corresponding to said points;

9 c) indexing each of said I/O circuit currents and said average logic current
10 demand per node to the node in said model closest to the corresponding I/O circuit
11 location;

12 d) solving the resistance and current source model resulting from step (c) for
13 voltages at the nodes; and

14 e) outputting the results.

1 2. The method of claim 1, further comprising:

2 (f) comparing said results against specified voltage drop (IR) and
3 electromigration (EM) limits of said design to identify violations of said limits; and

4 (g) changing said I/O circuit placement locations to correct said violations.

1 3. The method of claim 2, further comprising

2 repeating steps (a) - (g) until step (f) does not identify any violations.

1 4. The method of claim 1, wherein said design utilizes an area-array type I/O
2 circuit distribution.

1 5. The method of claim 1, wherein said design utilizes a peripheral type I/O
2 circuit distribution.

1 6. The method of claim 1, wherein step (d) uses a sparse matrix solver.

1 7. A method comprising:

2 establishing a distribution of I/O circuits in a power distribution network of an IC
3 design;

4 generating a resistance model comprising resistivities at nodes corresponding to
5 said network;

6 relating currents of said I/O circuits and an average logic current demand per node
7 to nodes in said resistance model;

8 solving for voltages at said nodes in terms of said resistivities, I/O circuit currents
9 and average logic current demand per node;

10 identifying ones of said voltages not in compliance with IR and EM limits of said
11 design; and

12 re-arranging said distribution to bring said identified voltages into compliance.

1 8. The method of claim 7, further comprising adjusting a granularity of said
2 resistance model for a desired accuracy of said model.

1 9. The method of claim 7, further comprising using lumped resistance values
2 to represent routing layers of said design in said model.

1 10. The method of claim 7, wherein said solving step comprises:
2 formulating a conductance matrix from said resistance model and a current matrix
3 from said I/O circuit currents and average logic current demand per node;
4 calculating voltages at said nodes using relationships between said conductance
5 matrix and said current matrix established by said relating step.

1 11. The method of claim 7, wherein said identifying step comprises:
2 comparing said voltages against a design rule specifying an allowable variation of
3 said voltages as a percentage of a supply voltage.

1 12. The method of claim 7, wherein said step of generating a resistance model
2 comprises:

3 repeating a bus pattern by a repeat factor, said bus pattern including a bus starting
4 location, a bus width and a bus end.

1 13. A computer-usable medium storing computer-executable instructions, said
2 instructions when executed implementing a process comprising:

3 from a power distribution network for an IC design, generating a resistance model
4 comprising resistivities at nodes corresponding to said network;

5 relating currents of I/O circuits connected to said network, and an average logic
6 current demand per node, to nodes in said resistance model;

7 solving for voltages at said nodes in terms of said resistivities, I/O circuit currents
8 and average logic current demand per node; and

9 outputting the results, said results identifying ones of said voltages not in
10 compliance with IR and EM limits of said design.

1 14. A program storage device readable by a machine, tangibly embodying a
2 program of instructions executable by the machine to perform method steps of
3 performing power distribution analysis for I/O circuits in an integrated circuit (IC)
4 design, said I/O circuits having defined placement locations within a power distribution
5 network of said design, comprising the steps of:

6 a) calculating maximum and average currents for each of said I/O circuits,
7 and an average logic current demand per node;

8 b) creating a resistance model of said power distribution network comprising
9 nodes and resistors corresponding to points on buses of said network and resistivities
10 corresponding to said points;

11 c) indexing each of said I/O circuit currents and said average logic current
12 demand per node to the node in said model closest to the corresponding I/O circuit
13 location;

14 d) solving the resistance and current source model resulting from step (c) for
15 voltages at the nodes; and

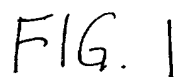
16 e) outputting the results.

1 15. A computer system comprising:
2 a memory containing computer-executable instructions;
3 a processor coupled to said memory for executing said instructions, said
4 instructions when executed performing a process comprising:
5 from a power distribution network for an IC design, generating a resistance model
6 comprising resistivities at nodes corresponding to said network;
7 relating currents of I/O circuits connected to said network, and an average logic
8 current demand per node, to nodes in said resistance model;
9 solving for voltages at said nodes in terms of said resistivities, I/O circuit currents
10 and average logic current demand per node; and
11 outputting the results, said results identifying ones of said voltages not in
12 compliance with IR and EM limits of said design.

METHOD OF POWER DISTRIBUTION ANALYSIS FOR I/O CIRCUITS IN ASIC DESIGNS

ABSTRACT OF THE DISCLOSURE

A method and system for testing the compliance of a distribution of I/O circuits in a semiconductor chip with voltage (IR) and electromigration (EM) limits. Maximum and average currents for the I/O circuits are calculated. A resistance model for the power distribution network of the chip is created, and the I/O circuit currents are indexed to corresponding nodes in the resistance model. Average current demand of the logic circuitry of the chip is also calculated and indexed to nodes in the resistance model. The resistance model with indexed currents is then solved to determine voltages at the nodes. The voltages are checked for compliance with IR and EM limits, and a report is produced. If violations of the IR and EM limits are detected, the placement of the I/O circuits in the power distribution network may be revised to bring the design into compliance with IR and EM requirements.



Power Bus of AAF ASIC: M4 & M6 vertical, M5 horizontal

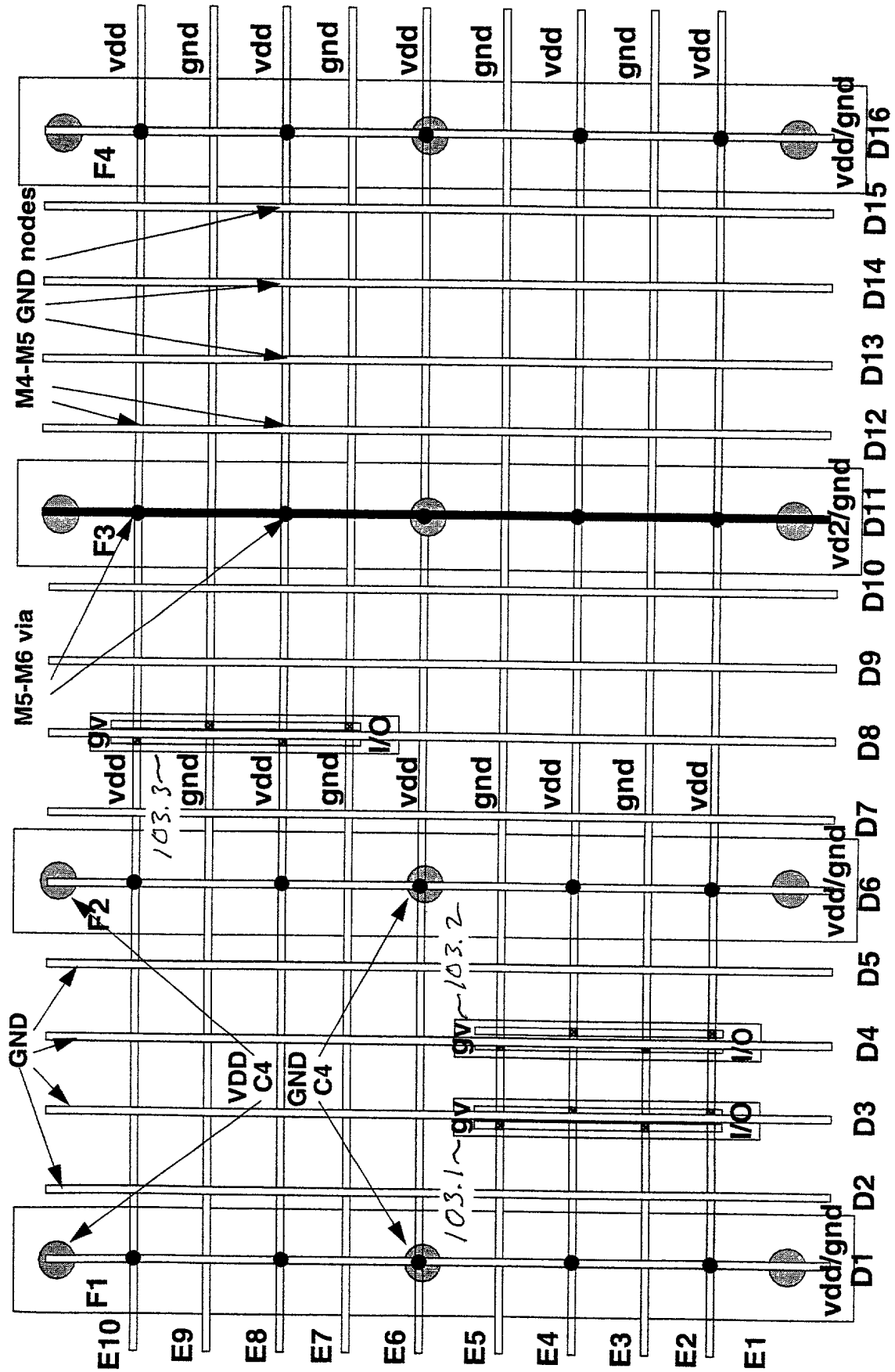


FIG. 3

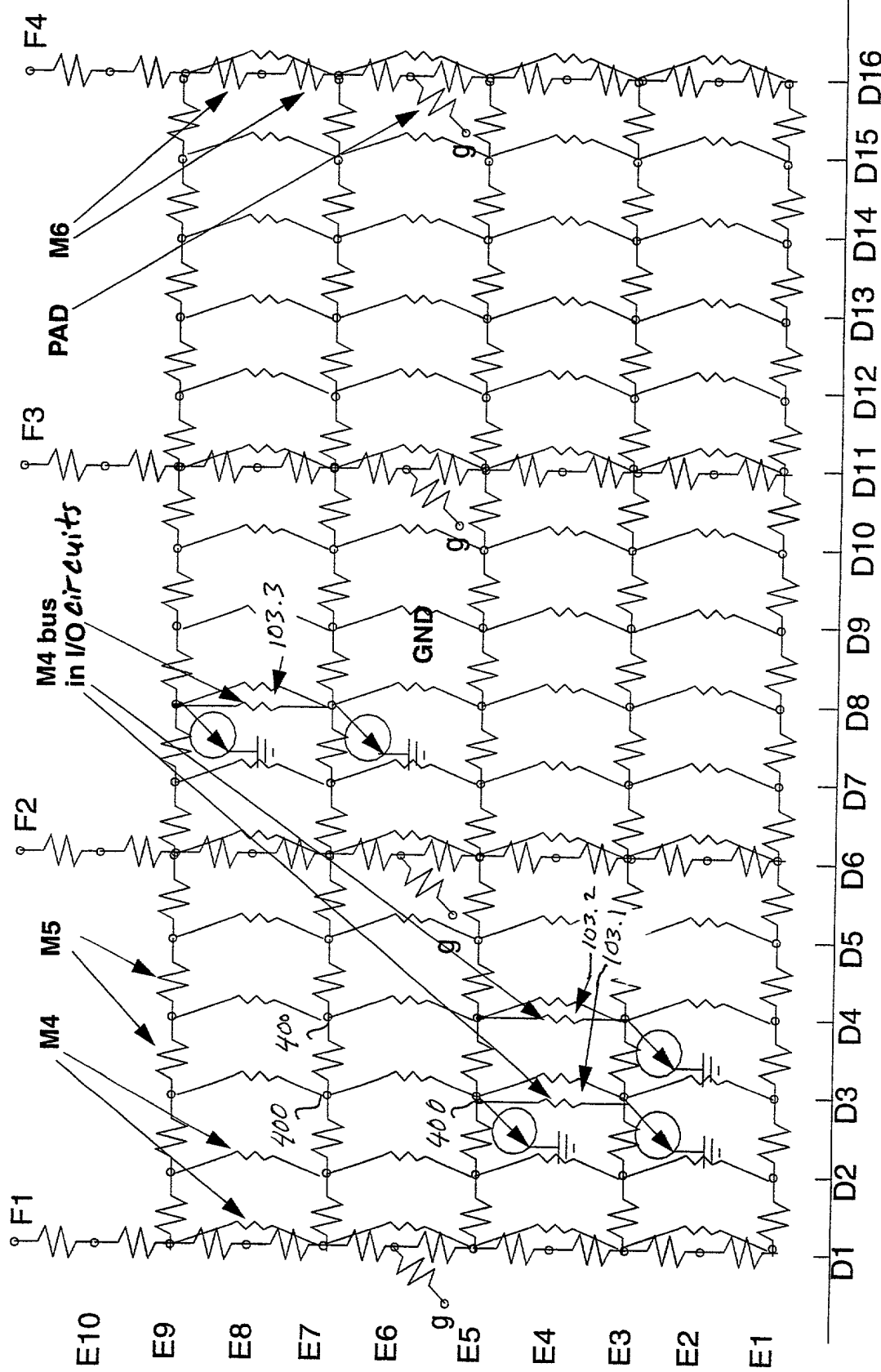


FIG. 4

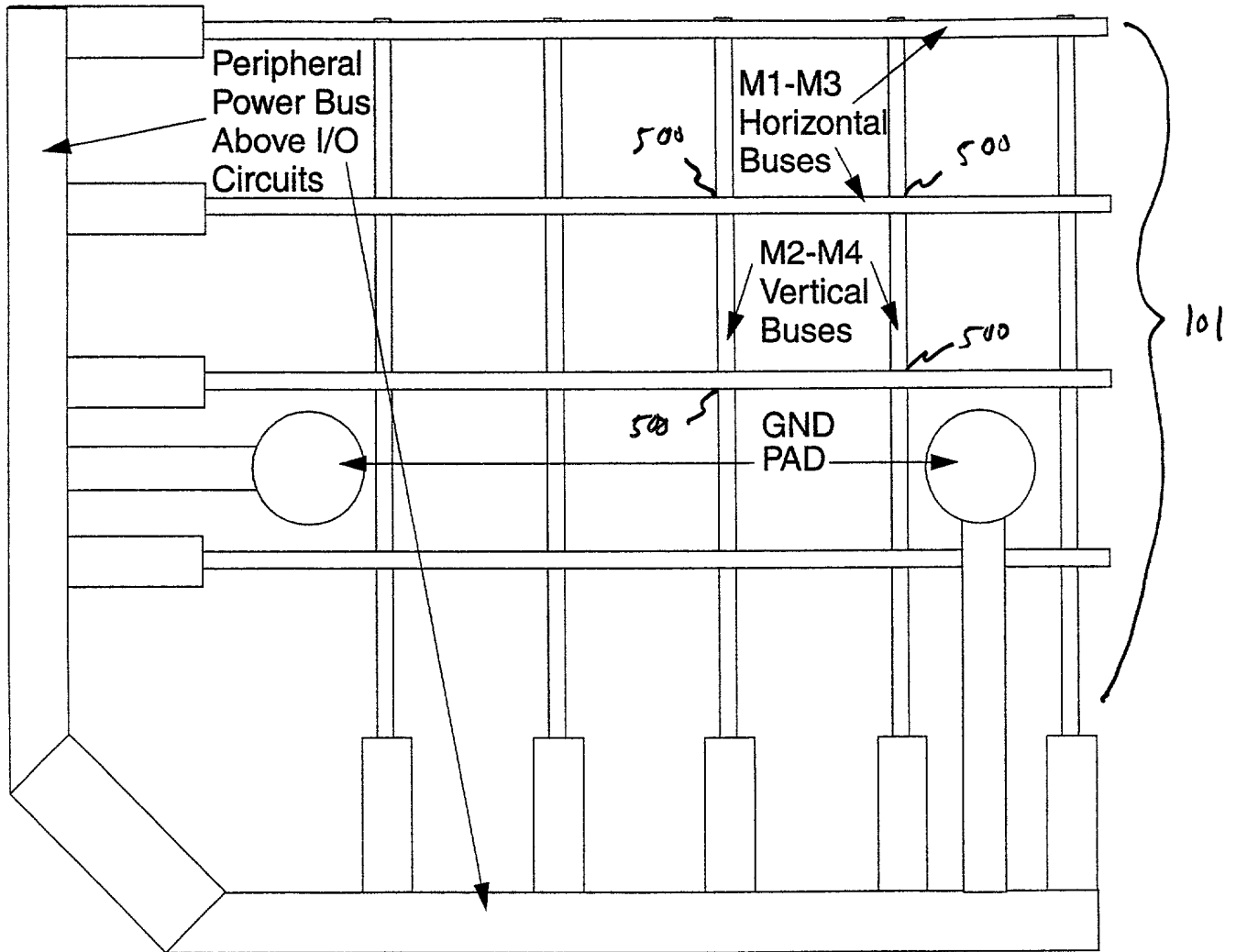


FIG. 5

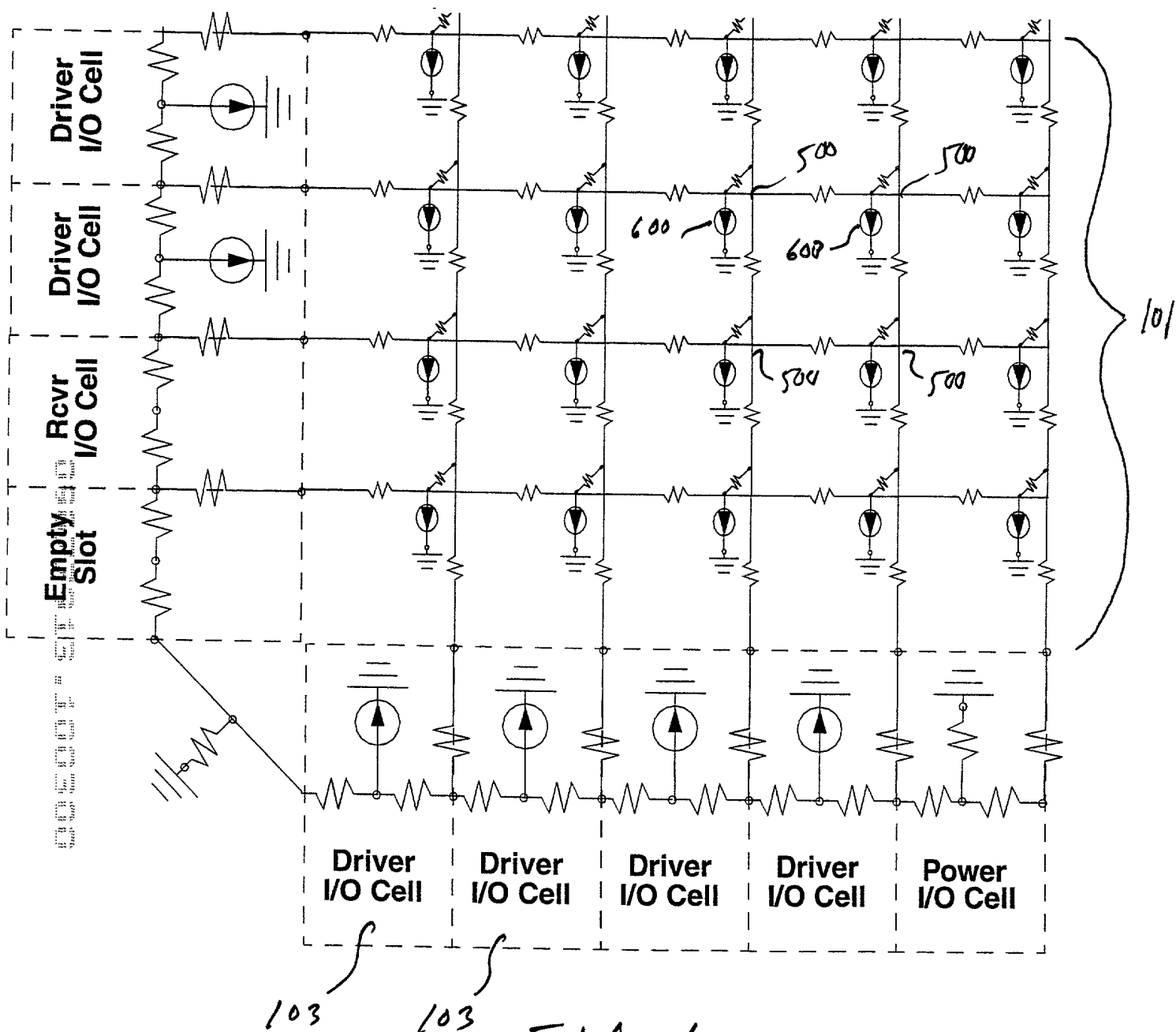


FIG. 6

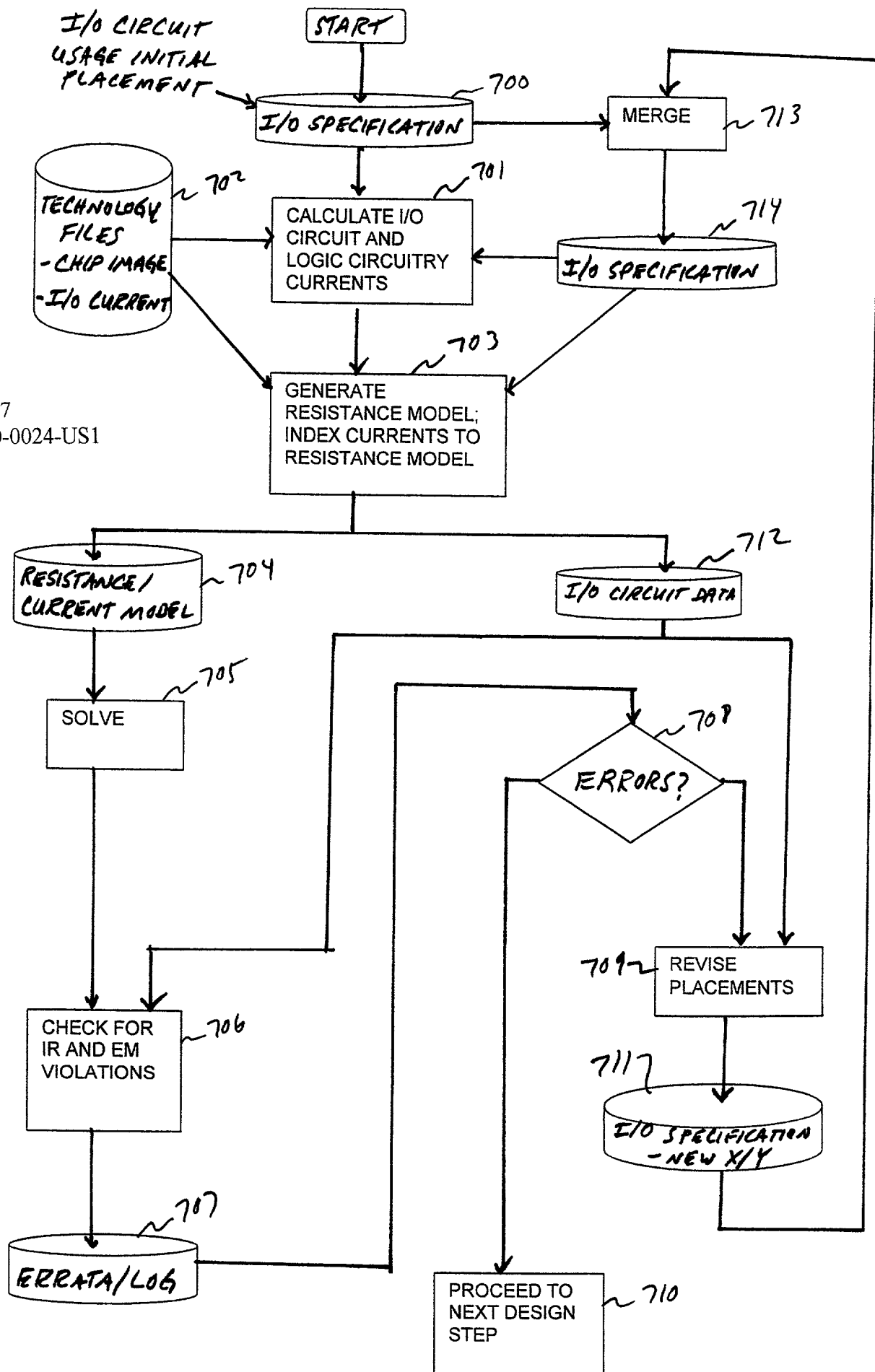


FIG. 7

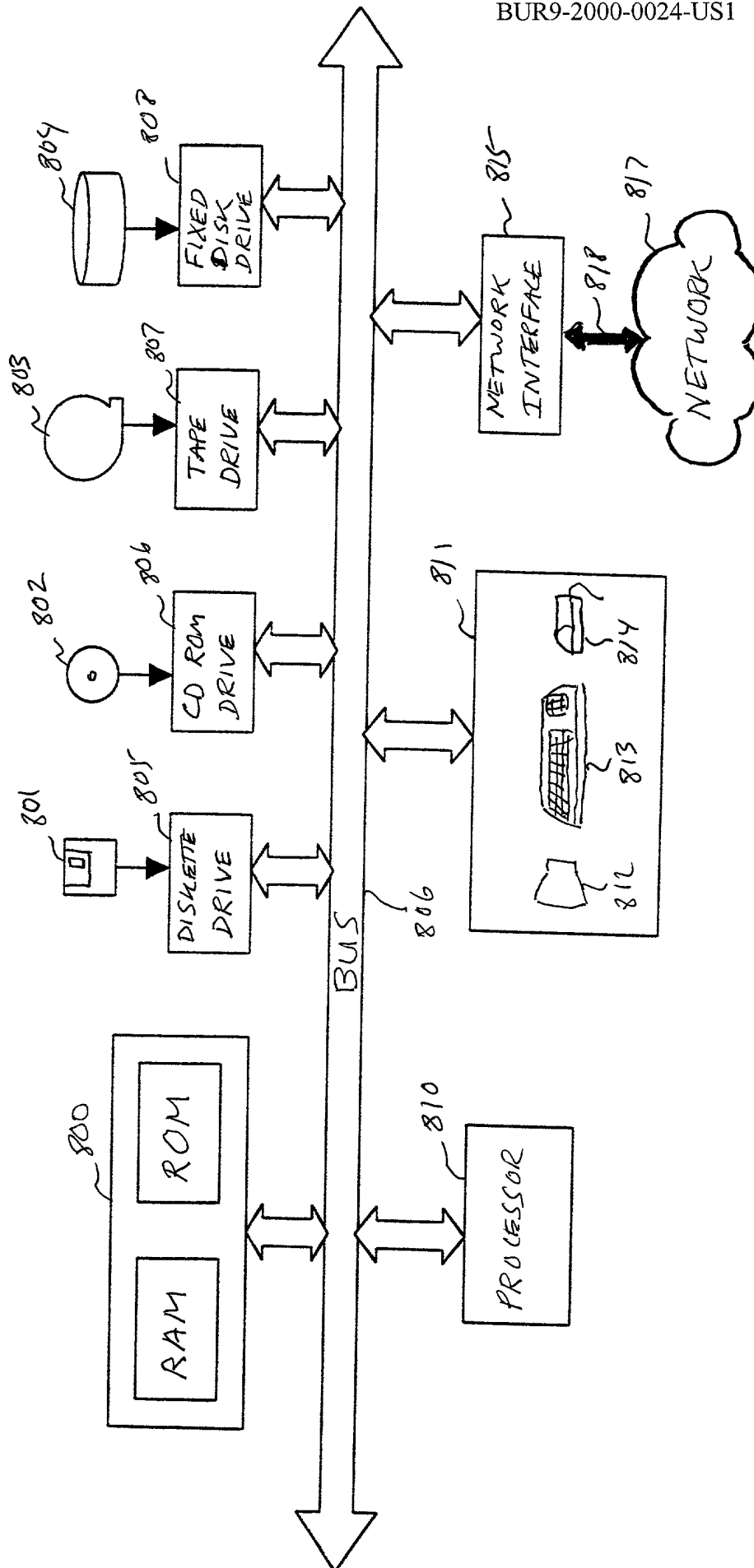


FIG. 8

Express Mail Label No. EK782889465US

DECLARATION FOR PATENT APPLICATION
English Language Declaration

As a below-named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

METHOD OF POWER DISTRIBUTION ANALYSIS FOR I/O CIRCUITS IN ASIC DESIGNS

the specification of which
(check one)



is attached hereto.



was filed on _____, as United States Patent Application Serial No. or PCT
International Application Number _____, and was amended on _____
(if applicable)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with 37 CFR § 1.56(a).

I hereby claim foreign priority benefits under 35 U.S.C. § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate listed below, or § 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

(Application No.)

(Country)

(Day/Month/Year Filed)

[]
YES

Priority Claimed

[]
NO

I hereby claim the benefit under Title 35, United States Code § 119(e) of any United States provisional application(s) listed below:

(Application Serial No.)

(Filing Date)

I hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s) listed below

Express Mail Label No. EK782889465US

and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by 35 U.S.C. § 112, first paragraph, I acknowledge the duty to disclose material information as defined in 37 CFR § 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.)

(U.S. Filing Date)

(Status)
(patented, pending, abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements are made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. § 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith: *(list name and registration number)*

Mark F. Chadurjian, Reg. No. 30,739; Richard A. Henkler, Reg. No. 39,220; Richard M. Kotulak, Reg. No. 27,712; James M. Leas, Reg. No. 34,372; William D. Sabo, Reg. No. 27,465; Eugene L. Shkurko, Reg. No. 36,678; Robert A. Walsh, Reg. No. 26,516; Howard J. Walter, Jr., Reg. No. 24,832; all of INTERNATIONAL BUSINESS MACHINES CORPORATION; George Vande Sande, Reg. No. 17,276, Burton A. Amernick, Reg. No. 24,852, Richard Wiener, Reg. No. 18,741, Townsend M. Belser, Jr., Reg. No. 22,956; Morris Liss, Reg. No. 24,510, Martin Abramson, Reg. No. 25,787, George R. Pettit, Reg. No. 27,369, Elzbieta Chlopecka, Reg. No. 32,767, and William E. Curry, Reg. No. 43,572, David W. Ward, Reg. No. 45,198, and John A. Evans, Ph.D., Reg. No. 44,100; all of POLLOCK, VANDE SANDE & AMERNICK; John E. Hoel, Reg. No. 26,279, Christopher A. Hughes, Reg. No. 26,914, Edward A. Pennington, Reg. No. 32,588; Joseph C. Redmond, Jr., Reg. No. 18,753; all of MORGAN & FINNEGAN, L.L.P.

Send Correspondence to:

William E. Curry
Pollock, Vande Sande & Amernick, R.L.L.P.
P.O. Box 19088
Washington, D.C. 20036-3425 U.S.A.
(202) 331-7111

and Direct Telephone Calls to: *(name and registration number)*

William E. Curry, 43,572.

3

Page 4 of 3
Docket No. BUR9-
2000-0024-US1

Express Mail Label No. EK78288

Full name of sole or first inventor	Gary S. Ditlow		
Inventor's Signature	<i>gary s. ditlow</i>	Date	10/3/00
Residence Address	Route 2 Box 53 Moog Road, Garrison, NY 10524		
Citizenship	USA		
Post Office Address	Same as residence		

Full name of second joint inventor (if any)	Robert A. Proctor		
Inventor's Signature	<i>Robert A. Proctor</i>	Date	10/2/00
Residence Address	45 Helen Avenue, South Burlington, VT 05403		
Citizenship	USA		
Post Office Address	Same as residence		

3

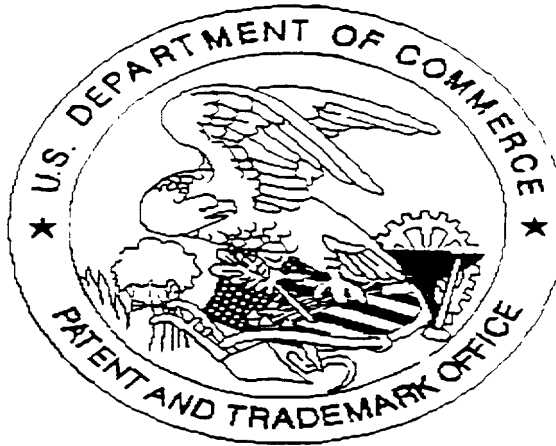
Page 4 of 3
Docket No. BUR9-
2000-0024-US1

Express Mail Label No. EK78288

Full name of sole or first inventor	Gary S. Ditlow		
Inventor's Signature		Date	
Residence Address	Route 2 Box 53 Moog Road, Garrison, NY 10524		
Citizenship	USA		
Post Office Address	Same as residence		

Full name of second joint inventor (if any)	Robert A. Proctor		
Inventor's Signature		Date	10/2/00
Residence Address	45 Helen Avenue, South Burlington, VT 05403		
Citizenship	USA		
Post Office Address	Same as residence		

United States Patent & Trademark Office
Office of Initial Patent Examination -- Scanning Division



Application deficiencies were found during scanning:

☒ Page(s) _____ of Express Mailing were not present:
for scanning. (Document title)

☐ Page(s) _____ of _____ were not present:
for scanning. (Document title)

☐ Scanned copy is best available.

SCANNED, # 12